Oscilloscope User's Guide

A close-up look at the high-performance general-purpose oscilloscope and how to use it for making tests and measurements

By Vaughn D. Martin

If you recently purchased an oscilloscope (or have had one for some time, for that matter) and want to use it effectively, you will have to become thoroughly familiar with all its controls and how to use them. Failure to do this will shortchange you on the sizeable investment you (or your employer) made for this powerful and versatile test instrument.

At the very least, the typical scope is a device that displays visual images of electrical waveforms and, as such, is extremely informative. But the scope is also a very effective measuring instrument as well. For example, depending on how you use it, your scope can serve as a sensitive ac or dc voltmeter or ammeter, a frequency counter, or a phase-difference meter. It can also serve as an indicator of short and open circuits, a component condition tester, or a semiconductor (diode and transistor) junction tester. In fact, the more you learn about your scope, the more you will discover you can do with it.

In this article, we will explore scope controls and functions, suggesting methods to use to make various tests and measurements. Since control layouts and features vary from one manufacturer to another, our procedures will be specific to the Textronix 2200 Series of scopes. This series is representative of modern, relatively low-cost, high-performance scopes. Therefore, the information presented should be readily transferrable to any of a number of different scope brands, whether B&K-Precision, Beckman, Leader, or other makes.

The two models that make up the Tektronix 2200 Series are the 2213 single-timebase delayed and the 2215 dual-timebase delayed scopes. The two differ only slightly, mainly in the triggering section. Note in Fig. 1 how the controls are logically arranged into five groups, each corresponding to a specific function. If you have a scope from a different manufacturer, you should be able to translate the procedures detailed to suit the particular model you have.

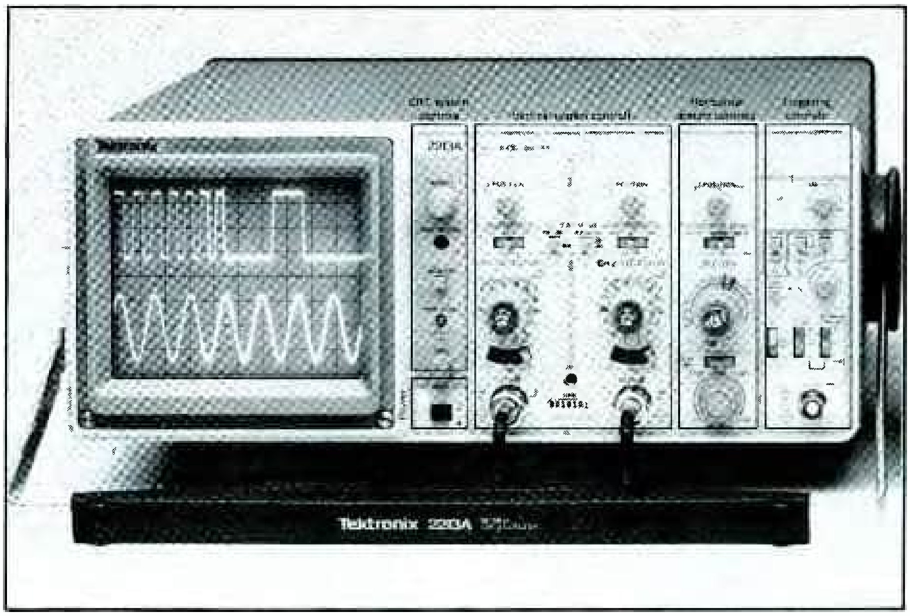


Fig. 1. Controls on front panel of Tektronix 2200 Series oscilloscopes (Model 2213 shown) are logically grouped according to function.

Getting Started

After unpacking your scope—and *before* you begin using it to make tests on your bench—it is important that you familiarize yourself with and check out the operation of all its controls. At the same time, compensate any probes that may have come with the oscilloscope.

Most measurements made with an oscilloscope require use of an attenuator probe (Fig. 2). Such probes usually have a switch on them. In one position, the switch passes the input signal directly to the scope's input. In the other position, the switch diverts the incoming signal to an attenuator network that divides the signal amplitude by 10 before delivery to the scope's input.

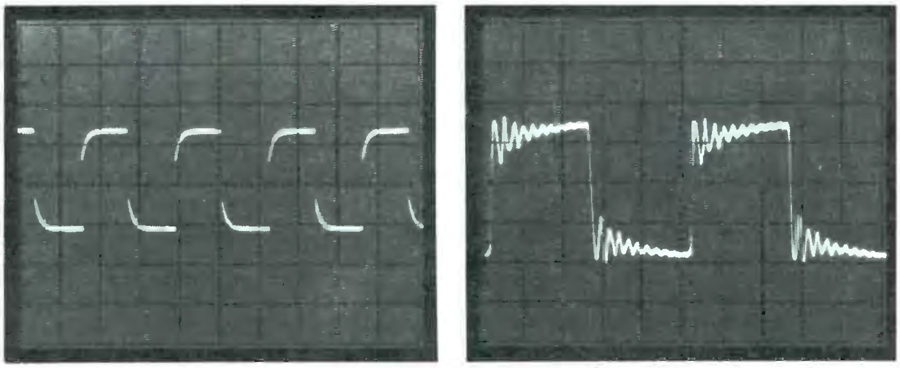
Compensation of a probe involves a simple procedure. After plugging the probe's cable into the desired scope input channel, you touch the probe tip to the internal calibrate output on the scope's front panel. Then you turn the tip in both directions while observing the screen. When the trace consists of a series of perfectly symmetrical square waves with no sign of sloping or "ringing," the probe is compensated.

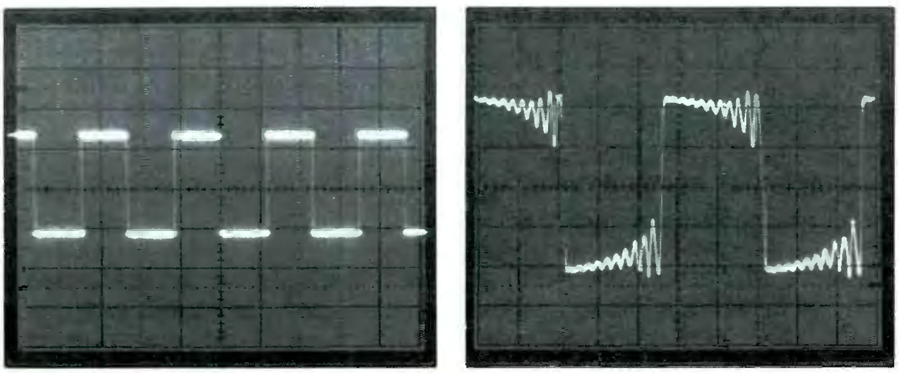
If your scope has more than one channel, each should have a probe specifically compensated for it. With any given input channel, use only the probe compensated for it. (Use some means of identification to keep track of probe/channel combinations.)

Figure 3 illustrates a series of waveforms that might be obtained as you compensate a probe. The two waveforms in the center represent what would be observed with a perfectly compensated probe. The top and bottom waveforms represent an overcompensated and an undercompensated probe, respectively. The photos on the left are the waveforms obtained as a probe was being compensated.

The photos on the right in Fig. 3 represent a 1-MHz square wave obtained with various probe conditions. Before you conclude that all three waveforms are identical, note

Fig. 2. Most measurements with a scope require use of attenuator probes, like this Tektronix one.


UNDERCOMPENSATED


COMPENSATED

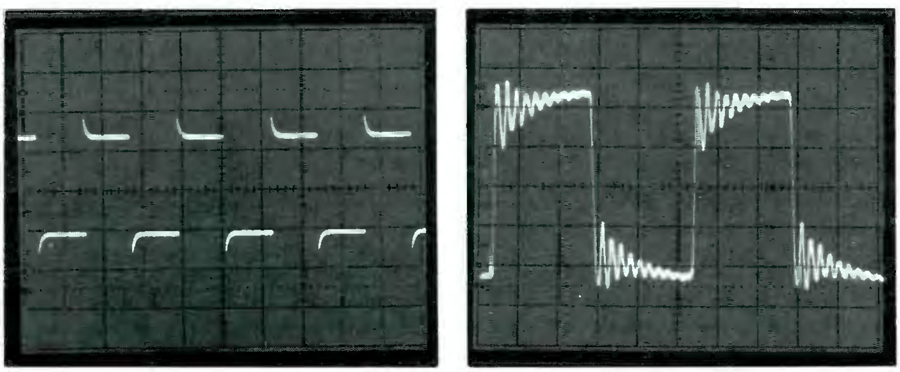

OVERCOMPENSATED

Fig. 3. Improperly compensated probes can distort waveforms displayed on the CRT screen. Shown here are probe-adjustment and 1-MHz square-wave signals as they appear with proper and improper compensation. Note amplitude and ringing on the square wave (right) with different compensation.

carefully how the center trace traverses 4.5 voltage intervals and the 1-MHz square waves with an undercompensated probe has only a 3.5-division peak-to-peak amplitude. With an overcompensated probe, the ringing on the square wave, which represents the probe's ability to settle down and allow the scope to display the actual shape of the square wave, is far greater.

Getting Acquainted

Before you can effectively use your scope, you must become acquainted with its various controls and how to use them to perform a variety of tests and measurements. The following should help you get started.

There are a number of scope calibrators made expressly for checking out the vertical and horizontal controls of a scope. The procedure for using them is as follows:

•Check all vertical controls: Variable controls (CH 1 and CH 2 VOLTS/DIV) should be in their detented calibrated positions. Make sure CH 2 is not inverted, unless you want it to be. Check the vertical mode switches to make sure the signals from the proper channels will be displayed. Check the two vertical VOLTS/DIV switches for correct settings, and do not forget to use the VOLTS/DIV readout that matches the probe setting (×1 or ×10). Check the input coupling switches; use DC for direct coupling or AC for alternate coupling.

•Check the horizontal control settings: Magnification should be off (red CAL knob on the SEC/DIV switch pushed in). Set the SEC/DIV switch to its detented calibrated position. Make sure the horizontal mode switch is set where you want it to be—NO DLY for no delay, INTENS when you want an intensified zone, or DLY'D for delayed sweep (A, ALT or B for the Model 2215).

•Check the trigger system controls to make sure your scope will select the correct slope on the trigger signal. Also, make sure the trigger holdoff control is at its minimum setting.

Amplitude And Time Measurements

These are the two most fundamental measurements made with a scope. All others are derived from them.

Amplitude Measurements. To make these, do the following:

1) Connect the probe to CH 1 input and to the probe adjust jack. Attach the probe's ground strap to the collar of the CH 2 input. Make sure you use the probe compensated for channel 1 and all variable controls are set to their detented positions.

2) Set TRIGGER MODE to NORM for normal triggering and HORIZONTAL MODE to NO DLY (A for the Model 2215). Make sure channel 1 coupling is set to AC, TRIGGER SOURCE is set to INT, INT is set to CH 1, and VERTICAL MODE is on CH 1.

3) Use the TRIGGER LEVEL controls to display a stable trace. Move the VOLTS/DIV switch until the square wave is about five divisions high on the screen's graticule. Now adjust the SEC/DIV switch to obtain a display of two cycles. The settings should be 0.1 V on the VOLTS/DIV switch and 0.2 ms on the SEC/DIV switch.

4) Use the CH 1 VERTICAL POSITION control to move the square wave so that its top is on the second horizontal graticule line from from the top of the screen. Then use the HORIZONTAL POSITION control to move the trace so that the bottom of one cycle intersects the center vertical graticule line.

5) Count the number of major and minor divisions down the center vertical graticule line (assign whole numbers like 1, 2, etc., to major divisions and decimal numbers like .1, .2, etc., to minor divisions) and multiply by the setting of the VOLTS/DIV switch to obtain the value of the measurement. For example, 5.0 divisions times 0.1 volt equals 0.5 volt. (If the voltage of the probe adjust square wave in your scope is different from this example, it is because the signal is not a critical part of your scope and tight tolerances and exact calibration are not required.)

Time Measurements. These measurements are best made against the center horizontal graticule line. Use the instrument settings from above, centering the square wave vertically with the VERTICAL POSITION control. Then use the HORIZONTAL POSITION control to line up one rising edge of the square wave with the second from the left graticule line. Make sure the next rising edge intersects the next horizontal graticule line.

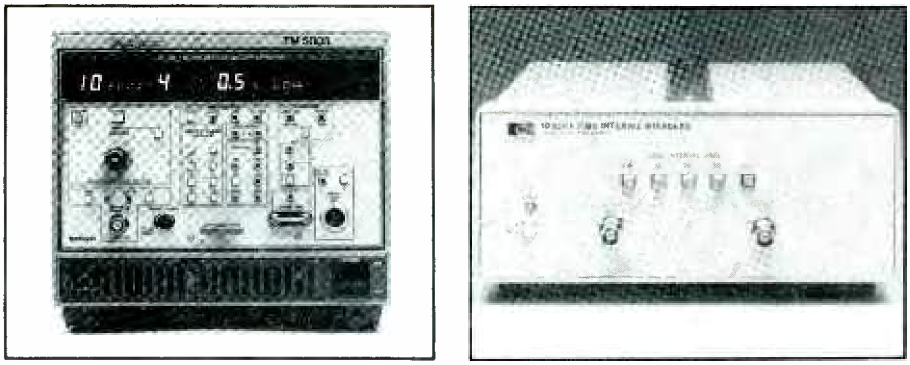


Fig. 4. The CG5001 programmable oscilloscope calibrator from Tektronix offers a wide range of test capabilities (A, left). Hewlett-Packard's 10236A time interval standard (B, right) offers outputs from 5 to 100 ns.

Count the major and minor divisions across the center horizontal graticule line from left to right and multiply by the SEC/DIV switch setting. For example, 5.7 divisions times 0.2 ms equal 1.14 ms. (Again, if the period of the probe adjust square wave in your scope is different from that obtained in this example, the signal is not a critical part of your scope's calibration.)

Derived Measurements

These are the result of calculations made from direct measurements like those previously cited. Frequently, pulse-width, phase and X – Y measurements are examples of derived measurements.

Pulse-Width Measurements. There are time intervals for generating very precise pulse widths (Fig. 4B). To quickly and easily measure the width of the probe adjust square-wave pulse, set your scope to trigger on and display channel 1. (Your probe should still be conntected to the channel 1 input and the probe adjust jack from the previous examples.) Use 0.1 ms/division and the NO DLY horizontal mode (A sweep for the Model 2215). Use AUTO triggering on the positive slope and adjust trigger level to obtain as much of the leading edge as possible on the screen. Switch the coupling on channel 1 to ground and center the baseline on the center graticule line.

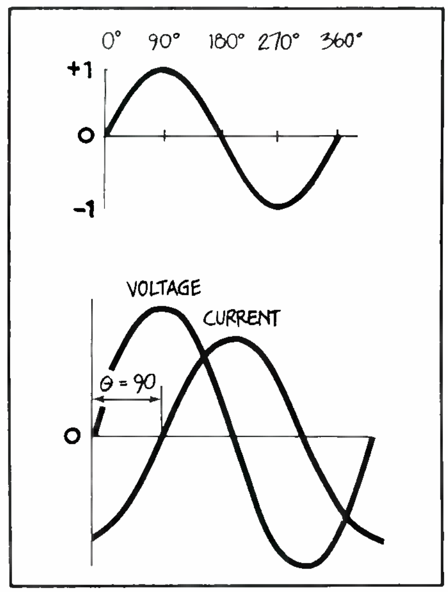
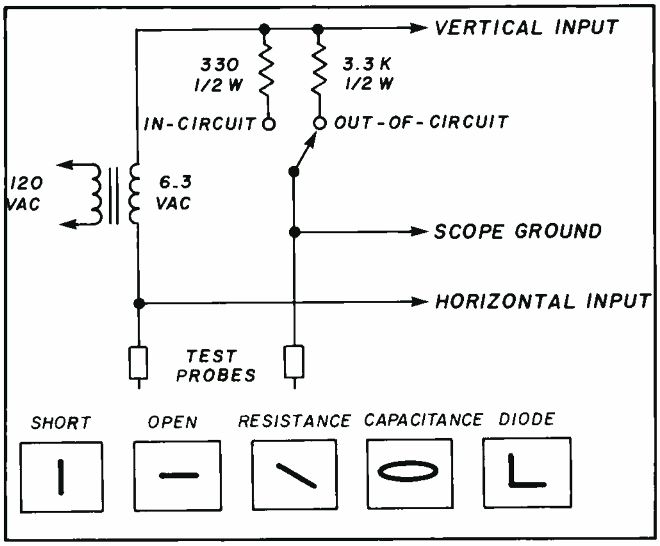


Fig. 5. To determine phase shift between two signals, measure distance between identical points on both, such as at the zero-crossing point.

Now use ac coupling to center the signal on the screen as you make pulse measurements at the 50% point of the waveform. Adjust the HORIZONTAL POSITION control to line up the 50% point with the first major vertical graticule line on the left side of the screen. Count the divisions and subdivisions along the center horizontal line. Multiply by the SEC/DIV setting to obtain pulse width.



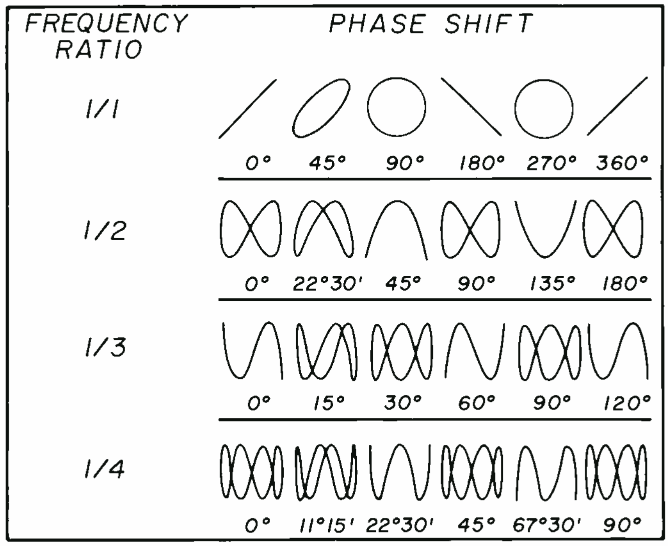


Fig. 6. Frequency measurements with Lissajous patterns require a sine wave of known frequency on one channel. This allows you to determine the frequency of any other signal applied to the other channel by interpreting the resulting pattern displayed on the scope's CRT screen.

Fig. 7. X-Y checking requires this transistor test circuit to be connected to a scope set to the X-Y mode. Patterns below schematic indicate the component's out-of-circuit condition. In-circuit patterns will differ because of resistors and capacitors associated with the component.

Phase Measurements. A waveform has phase, which is the amount of time that elapses since the onset of the cycle to a given point, measured in degrees. There is also a phase relationship that exists between two or more different-frequency waveforms, known as phase shift.

There are two ways to measure phase shift between two waveforms. One is to feed a separate waveform into each input of a dual-channel scope and view the two directly in the chop or alternate mode, with triggering on either channel. If you choose this method, adjust trigger level for a stable display, and measure the period of the waveforms. Then increase sweep speed to display something like the second drawing in Fig. 5. Measure the horizontal distance between the same points on the two waveforms. The phase shift is the difference in time between the two waveforms divided by the period and multiplied by 360 to obtain degrees.

The other method for measuring phase involves use of the scope's X-Y mode. On the front panel of the scope, you will find the vertical channel inputs labeled X and Y and the last position on the SEC/DIV switch labeled XY. When you use the XY position, the scope's time base is bypassed, and the channel 1 input signal becomes the vertical axis and channel 2 signals becomes the horizontal axis of the scope's display. In the X-Y mode, you can input a different sinusoid on each channel to display a Lissajous pattern, whose shape indicates the phase difference between the two signals. Examples of Lissajous patterns are shown in Fig. 6.

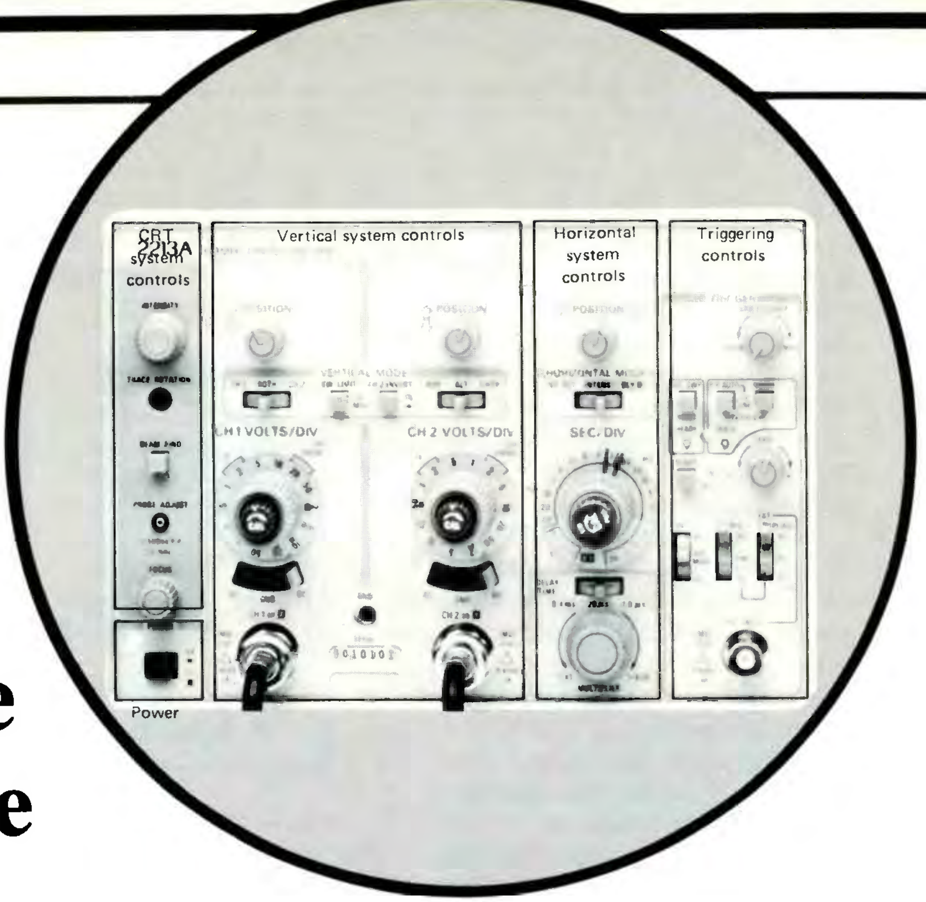
Phase measurements using Lissajous patterns are usually limited by the frequency response of the horizontal amplifier, which is typically designed with far less bandwidth than the vertical channels in an ordinary general-purpose scope. Specialized X-Y scopes and monitors, however, have almost identical vertical and horizontal systems and are therefore, more suitable for this measuring application.

X-Y Measurements. In addition to determining the phase shift of two sinusodial signals with a Lissajous pattern, the X-Y capability can also be used for other measurements as well. Lissajous patterns can be used to determine the frequency of an unknown signal when you have a signal of known frequency on the other channel. This frequency measurement can be very accurate, depending on how accurately you know the known signal to be and if both signals are *sine* waves.

Component checking in service and production situations is another X-Y application. It requires only a simple transistor checker, like that shown in Fig. 7.

There are many other applications for X-Y measurements in television servicing, engine analysis, and two-way radio servicing, to mention just a few areas. In fact, any time you have interdependent but not time-dependent physical phenomena, X-Y measurements are the way to go.

Next month, in the conclusion of this article, we'll go even deeper into the use of the oscilloscope for testing and measuring. **ME**



Oscilloscope User's Guide

Part 2 (Conclusion)

A close-up look at the high-performance general-purpose oscilloscope and how to use it for making tests and measurements

By Vaughn D. Martin

Last month, in Part 1 of this article, we introduced you to the high-performance, general-purpose oscilloscope and began telling you how to use it to make various types of measurements. In this concluding part, we continue with our discussion of how to use the scope in time-saving ways.

Differential Measurements

The ADD vertical mode and the channel 2 INVERT button on the 2200 Series scopes let you make differential measurements. Often differential measurements eliminate undesirable components from a signal being measured (Fig. 8). If you have a signal that is very similar to the unwanted noise, the setup is simple: Feed the signal with the spurious information into channel 1; feed the signal that is like unwanted components into channel 2; set both input coupling switches to DC (use AC if the dc components of the signal are too large); and select the alternate vertical mode by moving the VERTICAL MODE switches to BOTH and ALT.

Now set the VOLTS/DIV switches so that the two signals are about equal in amplitude. Then set the right-hand VERTICAL MODE switch to ADD and press the INVERT button so that the common-mode signals have opposite polarities.

If you use the channel 2 VOLTS/DIV switch and CAL control for maximum cancellation of the common signal, the signal that remains will contain only the desired part of the channel 1 input signal. The two common-mode signals will have canceled out, leaving only the difference signal.

Using The Z Axis

The scope's CRT has three axes: horizontal (X), vertical (Y), and intensity of the electron beam (Z). The input for the Z axis is usually located on the rear of the instrument. This input lets you modulate the intensity of the displayed signal on the screen, using an external signal. The Z-axis input will usually accept a signal of up to 30 volts peak-to-peak over a usable frequency range of dc to 5 MHz. Positive voltages decrease and negative voltages increase brightness, with 5 volts causing a noticeable change in intensity.

The Z-axis input is an advantage to users who have their instruments set up for a long series of tests. One example is the testing of high fidelity equipment (Fig. 9).

Using TV Triggering

The composite-video waveform consists of two fields, each of which contains 262 lines. Many oscilloscopes offer TV triggering to simplify viewing of video signals. Usually, however, the oscilloscope will trigger only on fields at some sweep speeds and lines at others. The 2200 Series scopes trigger on either lines or fields at any sweep speed.

To view TV fields with a 2200 Series scope, use the TV FIELD mode, which allows the scope to trigger at the field rate of the composite-video signal on either field. Since the trigger system cannot recognize the difference between the two fields, it will trigger alternately on the two and produce a confusing display if you look at one line at a time. To prevent this, add more holdoff time with the variable holdoff control or by switching the vertical operating mode to display both channels. This makes total holdoff time for one channel greater than one field period. Then position the unused vertical channel off-screen to avoid confusion.

It is important to select the trigger slope that corresponds with the edge of the waveform where the sync pulses are located. Selecting a negative slope for pulses at the bottom of the waveform allows you to see as many sync pulses as possible.

When you want to observe the TV line portion of the composite video signal, use the NORM trigger mode and trigger on the horizontal synchronization pulses for a stable display. It is usually best to select the blanking level of the sync waveform

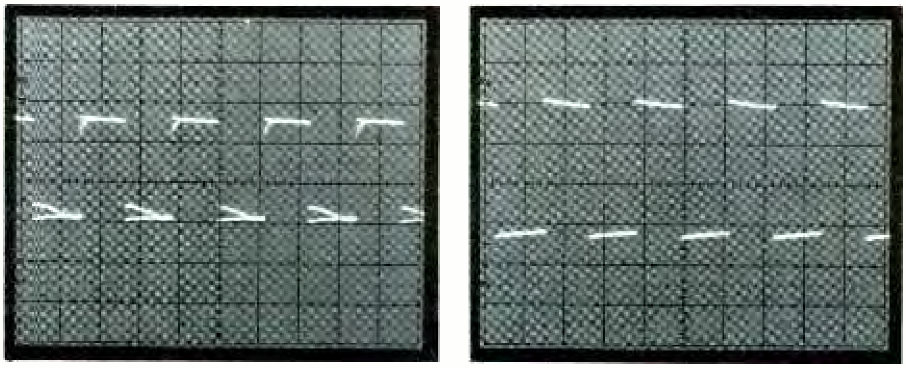


Fig. 8. Differential measurements allow removal of unwanted information from a signal any time there is a signal closely resembling the unwanted components. Once common-mode component is fed to channel 2 and inverted, signals can be added with ADD vertical mode (result shown in photo at right).

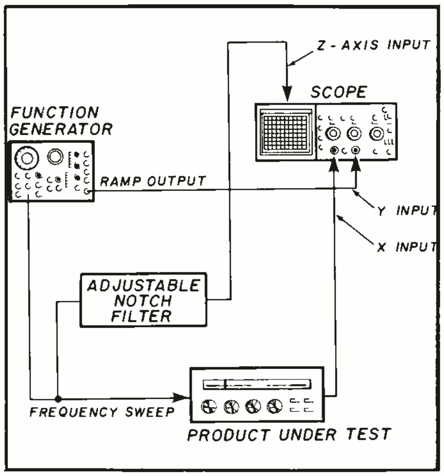


Fig. 9. This setup illustrates how a scope's Z axis, along with a sweep function generator and notch filter, can be used to test hi-fi equipment.

so that the vertical field rate will not cause double triggering.

Delayed Sweep Measurements

Delayed sweep is a technique that adds a precise amount of time between the trigger point and the beginning of a scope sweep. Delayed sweep is often used as a convenient way to make a measurement (the risetime measurement is a good example). To make a risetime measurement without delayed sweep, triggering must be on the edge that occurs prior the desired transition. With delayed sweep, you can trigger anywhere along the displayed waveform and use the delay time control to start the sweep exactly where you want.

Sometimes delayed sweep is the only way to make a measurement. Suppose the part of the waveform you want to measure is so far from the only available trigger point that it will not show on the screen. The problem can be solved with delayed sweep by triggering where you have to and using delay out to where you want the sweep to start.

The delayed sweep feature you will probably use most often is intensified sweep, which lets you use the delayed sweep as a positionable magnifier. You trigger in the usual way and then use the scope's intensified horizontal mode. The on-screen signal will now have a brighter zone after the delay time. Run the delay time (and intensified zone) out to the part of the signal that interests you. Then switch to delayed mode and increase sweep speed to magnify the selected waveform portion so that you can examine it in detail.

Single-Timebase Scopes

Very few single-timebase scopes offer delayed sweep measurement. Those that do may have measurement capabilities similar to those of the Tektronix Model 2213, which has three possible horizontal operating

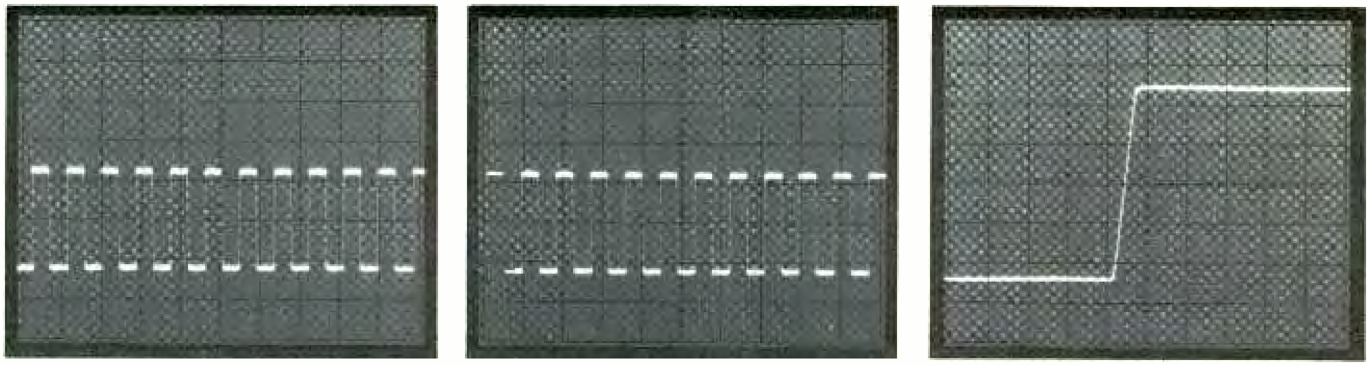


Fig. 10. Delayed sweep adds precise amount of time between trigger point (left) and beginning of sweep (center). By adjusting controls to display one transition of input waveform (right), you can obtain risetime measurement.

modes, labeled on the front panel NO DLY, INTENS and DLY'D.

When you set the HORIZONTAL MODE switch to NO DLY (no delay), only the scope's normal sweep functions. When you choose INTENS (intensified sweep), normal sweep will be displayed with an intensified trace after a delay time. The amount of delay is determined by both the DELAY TIME switch position. You can use 0.5 s, 10 s, or 0.2 ms and the DELAY TIME MULTIPLIER control, which lets you use from 1 to 20 times the switch setting. The DLY'D (delayed) position makes the sweep start after the selected delay. After selecting this position, move the SEC/DIV switch to obtain a faster sweep speed to examine the waveform in greater detail.

This list of horizontal modes should begin to give you an idea of how useful are these delayed sweep features. Start by making the risetime measurement described below. (Note that when making risetime measurements, you must take the risetime of the measuring instrument into account, as in Fig. 10.)

Dual-Timebase Scopes

Delayed sweep is normally found in dual-timebase scopes like the Model 2215, which have two totally separate horizontal sweep generators. In dual-timebase instruments, one sweep is triggered in the normal fashion while the start of the second sweep is delayed. To avoid confusion, we will call the delaying sweep the A sweep and the delayed sweep the B sweep. The length of time between the starts of the A and B sweeps is called the delay time.

Dual-timebase scopes offer all the measurement capabilities of single-timebase instruments, plus convenient comparisons of signals at two different sweep speeds; jitter-free triggering of delayed sweeps; and timing measurement accuracy of 1.5%. Most of this increase in measurement performance is possible because you can separately control the two sweep speeds and use them in three horizontal operating modes. In the Model 2215, these modes are A sweep only, B sweep only, and A intensified by B, as well as B delayed. The HORIZONTAL MODE switch controls the operating mode, and two SEC/DIV switches, concentrically mounted on the Model 2215, control the sweep speeds (Fig. 11).

When you use the ALT (alternate) position of the HORIZONTAL MODE switch, the scope displays the A sweep intensified by the B sweep and the B sweep delayed. As you set faster sweeps with the B SEC/DIV switch, you will see the intensified zone on the A trace diminish in size and the B sweep expanded by the new speed setting. As you move the B DELAY TIME POSITION control to change where the B sweep starts, the intensified zone will move across the trace and the B waveform will change.

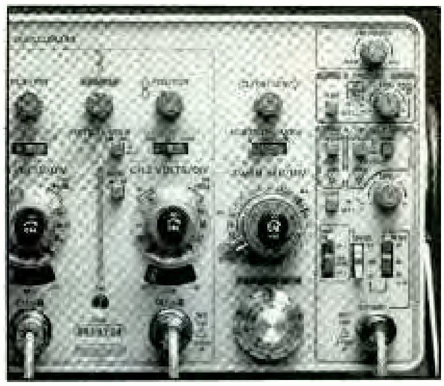


Fig. 11. Close-up of Tektronix's Model 2215 scope shows HORIZONTAL MODE *and two concentrically mounted* SEC/DIV *switches used for controlling sweep speed.*

This sounds more complicated than it really is. As you use the scope, you will find that the procedure, in fact, is very easy. You will always see exactly where the B sweep starts; and you can see the size of the intensified zone to judge which B sweep speed you need to make the measurement you want.

Measurement At Two Sweep Speeds

Examining a signal with two different sweep speeds simplifies making complicated timing measurements.

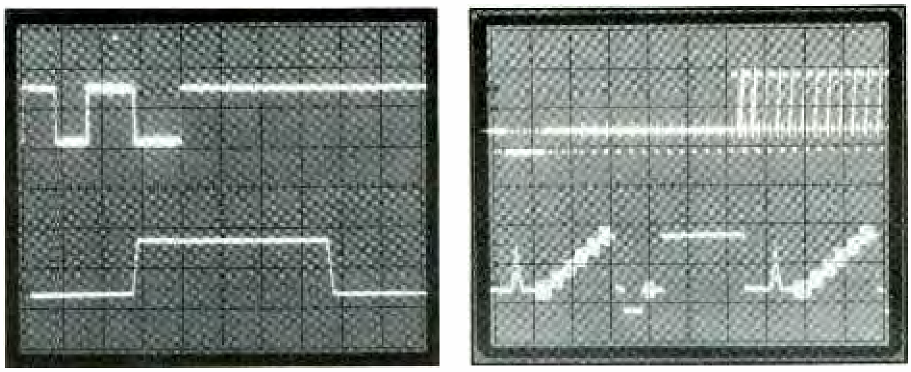


Fig. 12. Alternate delayed-sweep measurements are fast and accurate. One use (left photo) is examination of timing in a digital circuit. Another (right photo) shows one field of a composite video signal (upper waveform), where the intensified field is the lines magnified by the faster B sweep.

The A sweep gives a large slice of time on the signal to examine; the intensified zone shows where the B sweep is positioned; and the faster B sweep speeds magnify the smaller portions of the signal in great detail. You will find this capability useful in many measurement applications (Fig. 12).

Because you can use the scope to show A and B sweeps in channels 1 and 2, four traces can be displayed. To prevent overlapping traces, however, most dual-timebase scopes offer an additional position control, like ALT SWP SEP (alternate sweep separation) position on the Model 2215. With this and the two VERTICAL POSITION controls, all four traces can be placed on-screen without confusion.

Separate B Trigger

Jitter can prevent you from making an accurate measurement any time you want to examine a signal that is not perfectly periodic. With two timebases and delayed sweep, you can overcome this with the separate trigger available for the B sweep. Trigger the A sweep as usual and move the intensified zone out to the portion of the waveform you want to measure. Then set up for a triggered B sweep, instead of letting the B sweep simply run after the delay time.

On a Model 2215, the B TRIGGER LEVEL control does double duty. In its fully clockwise position, it selects the run-after-delay mode. In any other position, it is a trigger level control for the B trigger. The B TRIGGER SLOPE control lets you choose positive or negative transitions for the B trigger. These two controls let you set the scope to trigger a stable B sweep even when the A sweep has jitter.

Increased Timing Measurement Accuracy

In addition to letting you examine signals at two different sweep speeds and a jitter-free B sweep, a dual-timebase scope lets you get increased time measurement accuracy. Note that the B DELAY TIME POSITION control is a measuring indicator as well as a positioning device. The numbers in the window at the top of the dial are calibrated for the major divisions of the graticule, while the numbers around the perimeter divide each major division into hundredths.

To make timing measurements accurate to about 1.5% with the B DELAY TIME POSITION control, do the following: 1) use the B runs-after-delay mode; 2) place the intensified zone (or use the B sweep waveform) where the timing measurement begins and note the B DELAY TIME POSITION dial setting; 3) dial back to where the measurement ends and note the reading there; 4) subtract the first reading from the second and multiply by the A sweep SEC/DIV setting. You will find an example of this accurate—and easy—timing measurement in Fig. 12.

In Conclusion

Making an investment of several hundred to more than one thousand dollars to buy a high-performance general-purpose oscilloscope implies a commitment to better electronic testing and servicing. Naturally, this extends to learning how to use the instrument to its utmost capability to reap all of the benefits it has to offer. So be sure to set aside the time needed to fully acquaint yourself with your new scope. **ME**